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DESIGNING AND EXPERIMENTAL INVESTIGATION OF AN IMMERSION UNIT WITH DOUBLE GAS-CURTAIN SEALING FOR IMMERSION LITHOGRAPHY

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ABSTRACT

For most of the microelectronics industry history, optical lithography has been the backbone for continuing the trend of making features even smaller. The intention of immersion lithography is to increase the index of refraction in the space between the lens and wafer by introducing a high refractive index liquid in place of the low refractive index air that currently fills the gap. Because the liquid acts as a lens component during scan-step process, it must maintain a high and uniform optical quality. Thus, an immersion unit structure must be implemented to keep the flow field from leaking. After analyzing the mechanics of the flow-field in immersion lithography, an immersion unit structure with double gas-curtain sealing and gas-fluid mixing phase collecting was designed and implemented, featuring chemical surface characteristics. Experimental results were analyzed in terms of vacuum degree in collection antrum, input pressure for gas sealing, bubble-trap within flow field, double gas-curtain, double mixing-phase collection, surface characteristics of wafer.

KEYWORDS

Immersion lithography, Immersion unit, Gas sealing

INTRODUCTION

For most of the microelectronics industry history, optical lithography has been the backbone for continuing the trend of making features even smaller. However, as the apparent inability of optical lithography for future requirements, technology evolution to next-generation lithography (NGL) was becoming necessary.
Among all of the competing NGL technologies, Immersion lithography has been proposed in the past as a method to improve the resolution of optical lithography, but more recently it has been gaining popularity due its potential for achieving resolution down to 50 nm and below. It has shown promise as a technology extending optical lithography without significant changes to the manufacturing infrastructure used for decades [1, 2, 3].
The intention of immersion lithography is to increase the index of refraction in the space between the lens and

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wafer by introducing a high refractive index liquid in place of the low refractive index air that currently fills the gap. Because the liquid acts as a lens component during scan-step process, it must maintain a high and uniform optical quality. Thus, an immersion unit structure must be implemented to keep the flow field from leaking. Also, the immersion liquid within the gap has to be updated as substances unwrapped from chemical reacting may affect the optical quality of the liquid

IMMERSION UNIT MAIN STRUCTURE

Four generations of immersion unit structure have been developed up to present.

For the first generation of immersion unit, a basic liquid-transportation concept with double gas-curtain sealing and gas-fluid mixing phase collecting was designed and implemented

Improved porous medium processing was introduced for second generation, which has shown better performance with less vibration during gas-liquid phase mixing in liquid collection.

As for immersion unit generation three, continuous air sealing curtain along circumference direction within working area was implemented, providing enhanced air sealing performance, requiring smaller structure volume and less pressured air.

With inherited advantages from parental generation, No.4 generation of immersion unit was designed and implemented, aiming at integrated within an experiment platform for lithography scan-step moving and exposing.

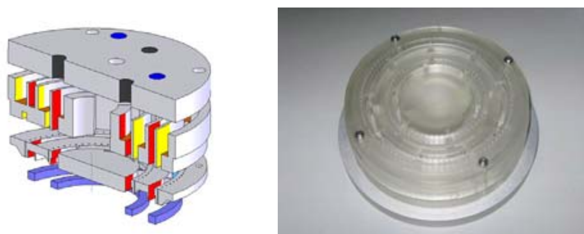

Figure 1 Generation one of immersion unit.

Figure 2 Generation tow of immersion unit.

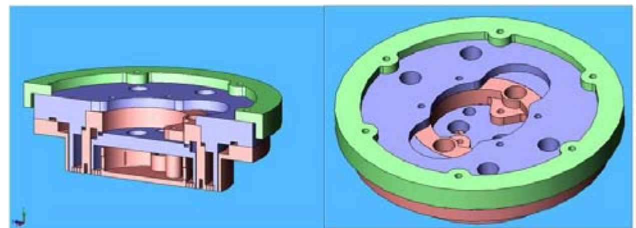

Figure 3 Generation three of immersion unit.

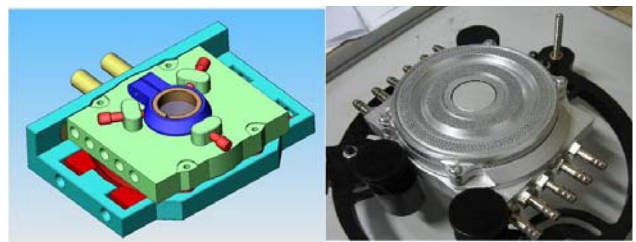

Figure 4 Generation four of immersion unit.

A schematic of the immersion unit implementation model is shown in Figure 5. Down-top and cross-sectional views of the lens/unit/gap/wafer system are illustrated [4].

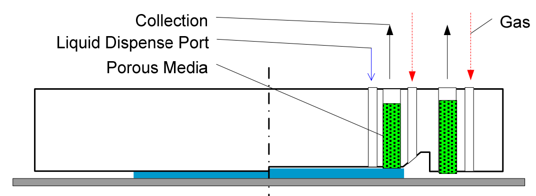

Figure 5 Schematic of the immersion unit structure implemented.

The immersion fluid is continuously injected through dispense ports that are located adjacent to the lens. Then the liquid is collected and removed from the wafer surface through collection ports that are located outboard of the dispense ports. Within the recovery channels, the porous media are applied to suppress vibration brought up by liquid/gas mixing phase collection. Certain negative

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pressure is provided within collection antrum, leading fluid pass under the lens. The wafer motion is oscillatory and characterized by velocities as high as 200 mm/s and accelerations as high as twice the acceleration of gravity, which will also improving the liquid motion and collection.

VACUUM DEGREE IN COLLECTION ANTRUM

Negative pressure is provided within the collection antrum for recovering immersion liquid from wafer surface. The proper vacuum degree is significant for flow field's completeness and non- leakiness. The classic gauge pressure is -25kPa corresponding to the classic liquid pumping pressure of 6kPa. Figure 6 illustrates the gauge pressure in collection antrum rise as a function of the liquid with different injecting pressure.

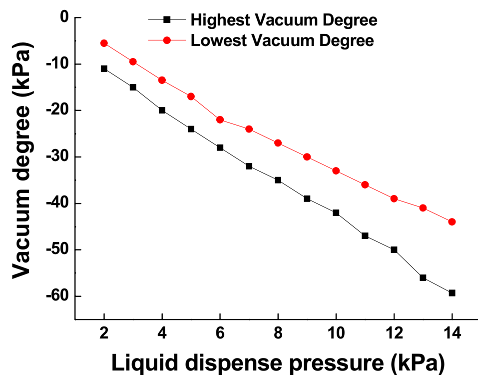

Figure 6 Collection antrum gauge pressure rise as a function of the liquid with different injecting pressure.

In terms of a specific liquid injecting pressure, the vacuum degree has a range of proper values. With the vacuum degree values lower than the range, recovering system will not be able to collect all the immersion liquid, leading to leakiness outboard immersion unit working area on the wafer. However, with the vacuum degree higher than the range, liquid from dispense ports will not be able to fill the gap flow field completely, destroying liquid phase continuity beneath the lens area. Experiment shows that increase the annular collection area offers wider range of vacuum degree acceptance region.

GAS SEALING PRESSURE

The wafer motion is oscillatory and characterized by velocities as high as 200 mm/s, and the immersion liquid leakiness is likely to occur as such relative motion between the contact line and the substrate. For higher scanning process speed, increasing the gas sealing pressure could maintain the intact gap flow field and avoid liquid leaking. Figure 7 illustrates the safe region with scanning speed rise as a function of gas sealing input pressure.

HYDROPHILIC AND HYDROPHOBIC SUBSTRATE

Wafers with different coating types are tested in scanning speed tolerance and vacuum degree threshold experiments. Figure 7 shows curves of acceptable scanning speeds as a function of gas sealing input pressure, with the substrate coating of titanium dioxide, silicon dioxide, and magnesium fluoride separately.

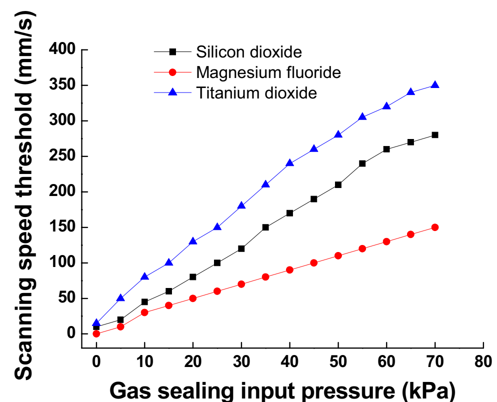

Figure 7 Acceptable scanning speeds as a function of gas sealing input pressure, with the substrate coating of titanium dioxide, silicon dioxide, and magnesium fluoride separately.

Titanium dioxide is extremely hydrophilic with a contact angle less than 10 degree, while magnesium fluoride is hydrophobic with a contact angle larger than 170 degree, and silicon dioxide coating in the middle of the range. Apparently, for an immersion unit structure with double gas-curtain sealing and gas-fluid mixing phase collecting, hydrophilic wafer surface supports higher speed threshold before gap flow field leaking.

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VELOCITY DISTRIBUTION

The flow field velocity contours are investigated, by computational fluid dynamics modeling, which are annulated around within the gap flow field beneath the lens area with double dispense ports. Through high speed camera sampling random particles' position at particular interval, velocity magnitudes are calculated and gathered, as illustrated in Figure 8. The overall velocity distribution slightly goes up as liquid injecting pressure increases.

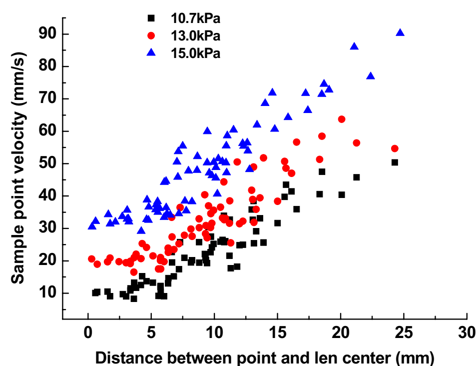

Figure 8 Random sample points velocity distribution as a function of point's center distance beneath lens area under different liquid injection pressure.

SUMMARY AND CONCLUSIONS

In this paper, the results of experiments on an immersion unit have been presented. Parametric studies have been carried out that analyze the important factors for improve the immersion unit working performance in terms of scanning speed tolerance and velocity distribution, including vacuum degree in collection antrum, input pressure for gas sealing, surface characteristics of wafer. Gas sealing pressures and vacuum degree in collection antrum that correspond to various liquid dispense pressure have been identified. Velocity distributions beneath lens area have also presented.

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